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MECHANICAL TESTING ANALYSES OF NEW ALUMINIUM ALLOY SPF TYPICAL-PARTS IN AIRCRAFT

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Abstract

This paper briefly presents the differences on strength of the typical aircraft structure components-hat-section parts, which are made of different materials by new process (SPF-Superplastic Forming) or conventional process. 7475 and Lc4 high-strength aluminium alloys are widely used in aircraft structures. These materials possess the superplasticity. 7475-02 (02-superplastic characteristics) and Lc4-02 are two kinds of materials with high hot-elongation (more than 450 percent). The fine grain size of them is about 10 μm. They can be formed into complicated parts under a particular temperature,stress and strain rate. The typical structural parts-hat-section specimens are made of 7475-02,7475,Lc4-02 or Lc4 and formed by advanced SPF technology or conventional STF (Stamping Forming) technology. The specimens will be compared in the different mechanical testing. The testing results are obtained from the tension-bend, the buckling and the fatigue test respectively. The comprehensive mechanical properties of 7475 are superior to Lc4. The fatigue property of the SPF specimens is similar to that of the STF specimens. 7475 SPF is widely applied in aircraft structure. The SPF technology has a good prospect because of it can save weight in structure design and cost less in manufacturing. In future, I think it will even bring a technological innovation in aircraft industry.

1. Introduction

Modern aircraft structural materials are aluminium, titanium, steel alloys and composite materials,etc.. Aluminium alloys are now the most common light metals used in the aircraft industry. It is also the main materials used in aircraft structures. It is estimated that the aluminium alloys used in the aircraft takes about 75 percent of the structure weight. Among the thin wall parts, about 80 percent are formed by tension, dropweight pressing,stamping,rollbending, etc.. The qualified rate of some complex shaped parts is very low and it would need several suits of molds and several times of intermediate annealing during the process. In order to solve this problem, designers have to divide a intergral component into several parts and then connect them together by bolting, riveting or welding. It would certainly increase the amount of manufacturing and connecting work and prolong the production cycle, as a result,the cost is increased. It would also increase the maintenace work and structural weight, lower its reliability as well as tactical-technical performance of an aircraft. With the development of mordern aircraft, the shape of its parts becomes more and more complicated and the contradiction of manufacture and design is more prominent. The development and application of shaping process of SPF high-strength aluminium alloys will have a wide prospect to aviation industry, it will make the manufacture engineering more rational and the structure weight lighter.

The mechanical tests are carried out on the specimens of 7475 and Lc4 aluminium sheets commonly used in aircraft. There are four kinds of used specimens. They are 7475 with SPF or STF and Lc4 with SPF or STF resoectively.

The specimens are compared to the different mechanical testing.The empirical results analyses have been obtained from tension-bend, buckling and fatigue testing respectively. Through the disscussion above, the prospect of design and technological process can be found.

2. Outline of the Hat-Section Specimens

Ratio of depth to width in the tensile and buckling specimens is 20/20=1.0 or 18/25=0.72. The fatigue specimens are taken out from the top of the hat-section parts. They are smooth parts and sizes of them are nonstandard.

2.1 High-strength materials of the specimens

7475 and Lc4 aluminium alloys are commonly used in aircraft and are selected for the specimens. 7475 is a kind of material with high-strength, good resistance to exfoliation corrosion, moderate fatigue strength and high fracture toughness. 7475 is widely applied in aircraft structures.Lc4 is a kind of material with higher strength than 7475, but its plasticity is inferiorer. Their chemical composi-

Alloys	Zn	Cu	Mg	Mn	Cr	Ti	Al	Fe	Si	other	
										each	total
7475	5.6	1.5	2.2	.06	.21	.06	Bel.	<.12	<.1	.05	.05
Lc4	6.0	1.7	2.3	0.4	.17	/	Bel.	<0.5	<.5	.05	0.1

TABLE 1 Chemical Compositions of Alloys (wt. %)

Alloy		Tensile strength MPa	Yield strength MPa	Elongation%		Modules GPa		Density g/ cm'	Fine grain size μm
				Cold	Hot	Ten.	Comp.		
7475	02'	528	460	>14	450	68.9	72.4	2.8	10
	T62	556	480		/				50
Lc4"	02	588	539	>9	450	66	65	2.85	10
	T6	620	580		/				50

* Supply by Alcoa U.S.A.

** Supply by Northeast Light Alloy Fabrication Plant P.R.China.

TABLE 2 Properties

tions and properties are listed in Table 1 and Table 2 respectively.

2.2 7475-02 and Lc4-02 superplastic fine grain sheets

The application of the SPF technology is a major developing direction in modern material science. Research has proved that pure aluminium and most of the aluminium alloys possess superplasticity. SPF of the aluminium alloys can be achieved by making the conventional aluminium ausformed,i.e., solution treatment. Thus, the alloy elements are to be solutionized into base material. After two periods of aging, a high density dispersion-precipitated particles are obtained. They will become recrystallized nucleus. Precipitated particles would be recrystallized at a particular temperature with the size about 10 μm approximately, after being deformed by hot rolling, then the equiaxed thin grains are obtained. The other way for getting fined grain and SPF is to adjust the chemical compsition by adding rare-earth elements, such as zr, etc., then over-cooling when solidified, see Fig.1. This SPF high-strength aluminium alloys can be formed into the parts with complicated shapes under a particular temperture, stress and strain rate, 7475-02 aluminium alloy SPF is widely used in aircraft industry.

2.3 Forming and making the specimens

The typical structural hat-section specimens are formed by STF and SPF. STF is a process of conventional technology. The SPF specimens is formed by a male die at the temperature between 490℃ and 510℃ with the strain-rate of 8.3X10^{4} sec^{1} and the sensitive exponent of 0.6. The pressure applied in different intervals comes from the calculated pressure-time curve. It will take about 30 minutes to make such a single hat-section part. The hat-section part is kept well close to its die. The largest thickness variation take place near by the R-corner.And the variation rate is about 45 percent. The thickness thin out smoothly and no necking-down and fracture are found. Its aluminium clad was nearly all alloyed. No defects are found in microstructure and there is no significant growth of grain. The rate of cavity in the specimens is about 0.3, see Fig. 2. The buckling specimens are taken out from the uniform section parts, see Fig.3. The smooth fatigue specimens are taken out from the top of the hat-section parts, see Fig. 4.

The number of the specimens see Table 3.

Alloy of Specimen	Number			
	Ten.-bend	Buckling	Fatigue	Sum.
7475-SPF	/	/	16	16
7475-STF	/	/	16	16
Lc4-SPF	10	5	5	20
Lc4-STF	12	10	16	38
Sum.	22	15	53	90

TABLE 3 Number of Specimens

3. The mechanical Testing Analyses

According to testing requirements the mechanical testing divided into three parts: tension-bend, bucking and fatigue testing Every specimen with strain gauges stuck on its sections is fastened on a special fixture. And loads are applied by a tensile (or fatigue) machine. The measurement process is controlled and all the measurement data are dealt in statistical method by computers. The average weights of the SPF specimens are about 8 percent lighter than those of the STF specimens.

3.1 Tension-bend

The 22 specimens of the hat-sections made of Lc4 sheets and formed by the two different processes are divided into two groups: 1' and 3' specimens.

To prevent stress concentration at the edges of the hat-sections, special fixtures must be designed. The loading accuracy at full range should not be more than 1 % loading process.

(a) Tensile load P.The average failure load of the SPF specimen has been reduced 12 percent compared with those of the STF specimens. The first reason is that the sideway deformation of the SPF specimens is smaller than that of the STF specimens after yield. The second reasion is that the measured web thickness of the SPF specimens has been reduced about 11-17 percent, compared with the STF specimens.

(b) P-ε curves. For each specimen, strain gauges are stuck on the three sections. Strain must be measured for each corresponding loading P. The measuring process is controlled by the computer. The data is printed by the comptuer printer too. The P-ε curves are shown in Fig. 5.

The tendency of the P-ε curves is the same within elasticity for the hat-sections formed by the two different processes. The slopes of the STF specimens are higher than that of the SPF specimens, which indicate that the deformations of the SPF specimens are more than that of the STF specimens. The SPF specimens become plasticity more early than the STF specimens. At this moment, the relations between P-ε is nonlinear. It is due to the differences between the parameters of the testing machine, the sizes of the each specimen and the quality of forming, this is a complex occurrence and it is difficult to explain clearly. Therefore further analysis is not treated in this paper.

(c) Analysis of the failure fracture. Compared with the STF hat-section specimen, the bottom of the SPF specimen is thinner,and the top of it is thicker. There are thirteen specimens broken in the middle and nine specimens broken near the edge of the flange. Fracture places of the partical specimens as shown in Fig. 6-9. The fractures are all occured on the sections which are perpendicular to the tensile stress. While the tensile load grow to some extent, the tensile stress would grow along the load direction till the fracture occures.It can be found that all the failure fractures of the specimens are sloping section about 45° to the tensile stress, showing grey color and fiber forming. They are typical shear-fractures, as shown in Fig. 10-11.

3.2 Buckling

The 15 uniform hat-section specimens made of Lc4 sheets are formed by two different processes. To prevent loading eccentricity, the specimens are fastened on a special loading reverse fixture, see Fig.12. The loading accuracy should not be more than 1%. It is a downwards unidirectional tensile loading and reverse fixture will apply a compressive load on the specimen.

(a) Buckling load.A sudden buckling failure took place in all specimens when the specimens went in critical state. The critical buckling loads of the specimens are scattered. The confidence level of the data is 95 percent. The critical buckling loads of the SPF specimens are 8 percent down compared with those of the STF specimens. The first reason is that the measured web thicknesses of the bottoms and sides in the SPF specimens have reduced about 5 percent compared with the STF specimens. The second reason is that the end fixity coefficient of the SPF specimens is about 5 percent smaller compared with the STF specimens.

(b) P-ε curves. Strain gauges are stuck on the mid-section of every specimen.Strain must be measured for each corresponding loading P.

The measuring process are controlled by the computer.The data are printed by the computer too. The P-ε curves are shown in Fig.13. The tendency of the P-ε curves is the same in the range of elasticity for the uniform hat-section formed by the two different process. The P-ε curves on the flange convexes (inner sides) will change the direction when average stresses on the flange convexes and concaves (outer sides) exceed the critical stresses.

(c) Analysis of the buckling failures. Both fracture types of the SPF and STF specimens are similar. They are typical local instability as shown in Fig. 14-15. There are eleven specimens are broken in the middle from the top to bottom of the hat-section part, see Fig. 16. The other four specimens are broken in the middle of the top in the hat-section part, see Fig. 17.

3.3 Fatigue

The 53 specimens of the unnotched non-standard elements are taken out from the top of the hat-section parts. The fatigue specimens are mode of 7475 or Lc4 sheets and formed by SPF or STF processes. They are divided into four groups: A' , B' , C' and D' specimens.

Geometrical stress concentration factor of the specimens is K_t =1.078, which is get from calculation. Fatigue testing is made for axial-tensile equiamplitude loading at frequencies varying from about 1 to 6 Hz. The term stress ratio (R) is 0.1. An automatic shut-off and cycle count is provided to record the cycles during the specimen' failure tests.

(a) Fatigue life. Fatigue test scatter is a plaguy problem due to the geometrical size of indentical specimens is virtually impossible. Degree of reliability is 50 percent and degree of confidence is 95 percent used in this testing. The data acquired from the test results which are shown in Table 4 indicate that the fatigue properties of the 7475 specimens are superior to those of the Lc4 specimens and the SPF specimens are similar to those of the STF specimens.

Specimens	σ.test MPa	K	f/sec	Cycles
A' 7475-SPF	286	0.5	6	39000
	400	0.7	2	18000
	486	0.85	1	6800
B' 7475-STF	278	0.5	6	57000
	389	0.7	2	20100
	472	0.85	1	11800
Lc4-SPF(C')	301	0.5	6	33000
D' Lc4-STF	280	0.5	6	54400
	392	0.7	2	19500
	476	0.85	1	10600

TABLE 4 Fatigue Life

(b) Analysis of the failure fractures.Fracture modes of fatigue test sheets see Fig.18.

For A' 7475 SPF specimens, the most of fatigue fracture modes are bevel fractures that can be observed ductile dimples on its fracture surface, and the rest of the fatigue fracture modes are flat fractures that can be observed paralleled fatigue striation, see Fig. 19.

B' 7475 STF specimens had gloomy flat fatigue fracture modes which no occurred fatigue sfriation, see Fig. 20.

D' Lc4 STF specimens had small anged bevel fracture modes which can observed ductile dimples on its fracture surface, see Fig. 21.

4. Conclusions

4.1 The comprehensive mechanical property of the high-pure and the high-tough 7475 aluminium alloy is superior to Lc4 aluminium alloy The static and fatigue properties of the SPF specimens are similar to those of the common STF specimens.

4.2 It is its main characteristics that a SPF hat-section has a thin bottom and a thick hat When a SPF hat-section is used, its bottom is usually connected to the panels. The result is that the geometric center of all the combined parts tends to the center line. Under the action of alternate inner and outer pressure or eccentric tension and pressure or bending moment, SPF hat-section can carry larger load than STF. Therefore, its structural efficiency can be brought into full play.

4.3 Ratio of the static or fatigue failure loads to weights of the SPF specimens are similar to those of the STF specimens.

4.4 The ratio of depth to width of the hat-section is between 0.72 to 1.0. Hat-sections can be manufactured successfully by using SPF method. The geometry, the section sizes and the ratio of depth to width described in this paper can be used as a reference for design.

4.5 Because of its very high hot elongation, 7475 SPF is easy to form very complicated parts without any clear necking and the deformation of the parts can last to a very large size in aircraft.

4.6 As SPF method needs fewer simple dies and assembly fixtures, fewer fasteners and parts and the ratio of qualified product is also high. When this kind of method is taken in design, the fabrication cost can be reduced about 30-50 percent and the structural weight can be saved about 20-30 percent. Especially when SPF is used in designing a complicated structure, the benefit of weight gained from it is more apparent, because of the parts and the fasteners involved in the structure are reduced a lot. According to some reparts, the reduction of the structural weight can bring us multiple benefits and bring a benign circle influence to an aircraft's tactical-technological properties.

4.7 SPF have a wide range of advantage for application as shown above. It will even I think, bring a technological innovation in aircraft industry.

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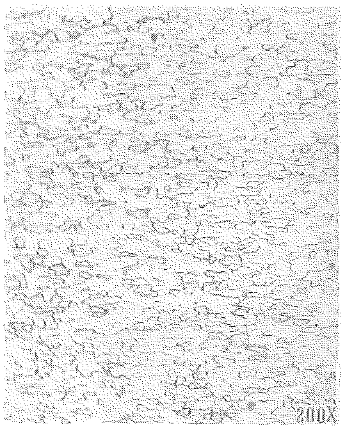

FIG.1 Microsturcture of the Superplastic Fine Grain Sheet

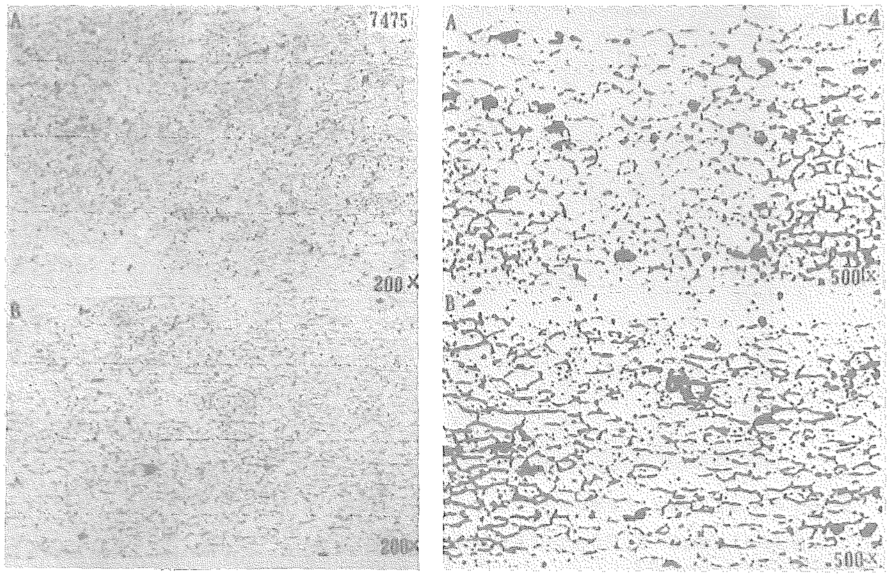

FIG. 2 Microstructure A. After SPF B. After SPF Quenching and Artifical Aging

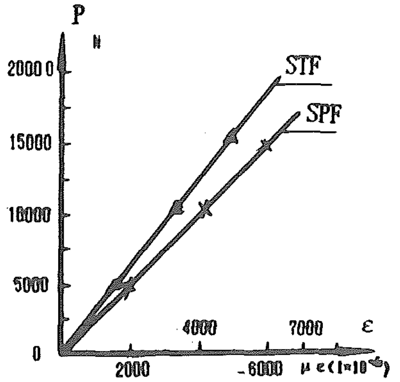

FIG.5 P-ε Curves of Tension-Bend

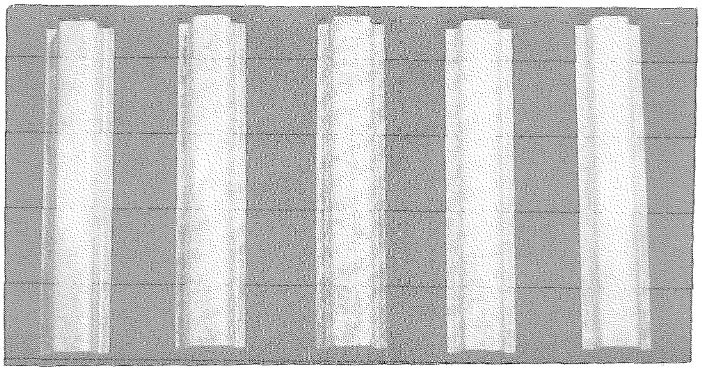

FIG. 3 Buckling Test Parts

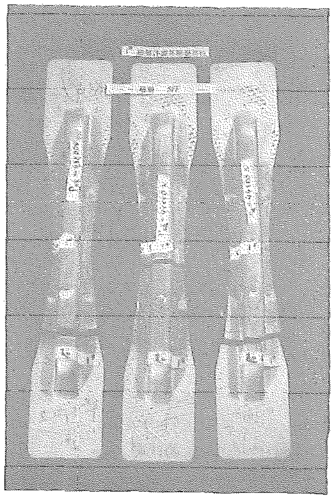

FIG.6 Failure Fractures of 1 SPF Specimens (Depth/Width=1.0)

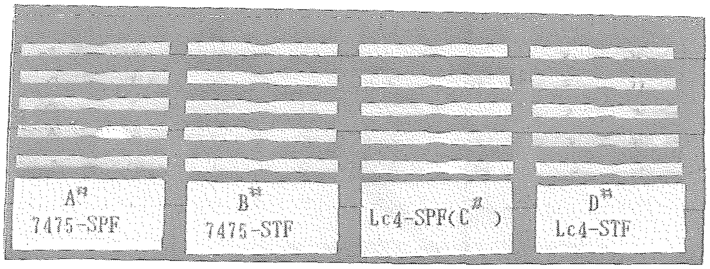

FIG. 4 Fatigue Test Sheets of A' 7475-SPF B' 7475-STF, C' Lc4-SPF and D' Lc4-STF

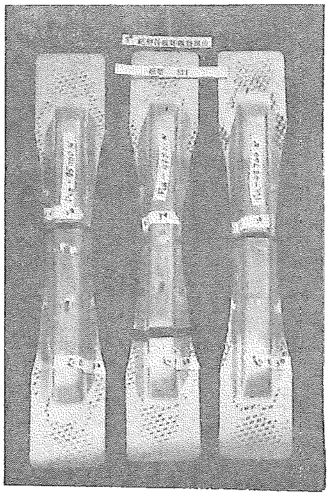

FIG.7 Failure Fractures of 3 SPF Specimens (Depth/Width=0.72)

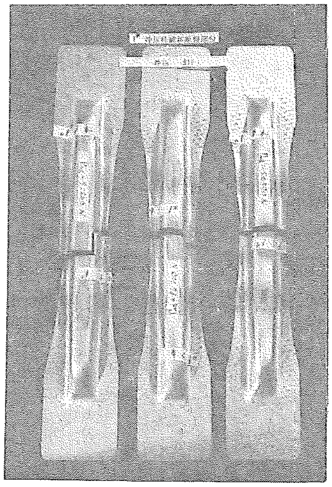

FIG.8 Failure Fractures of 1 STF Specimens (Depth/Width=1.0)

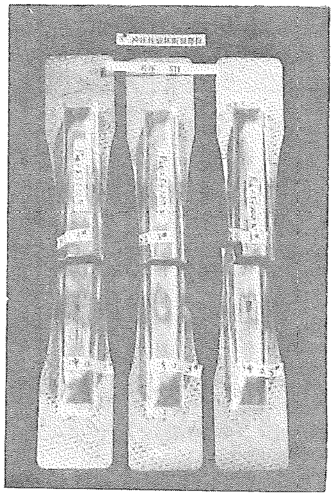

FIG.9 Failure Fractures of 3 STF Specimens (Depth/Width=0.72)

FIG. 10 Typical Shear Failure Fractures of SPF Hat-Section Parts

FIG. 11 Typical Shear Failure Fractures of STF Hat-Section Parts

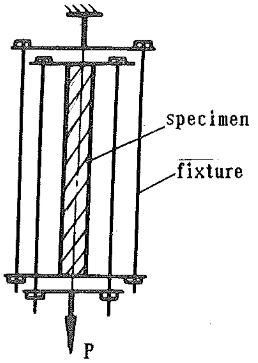

FIG.12 Schematic Diagram of the Special Loading Reverse Fixture

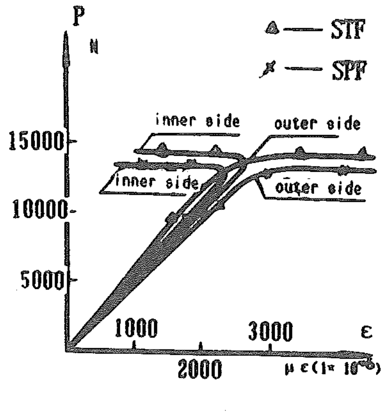

FIG.13 P-ε Curves of Buckling

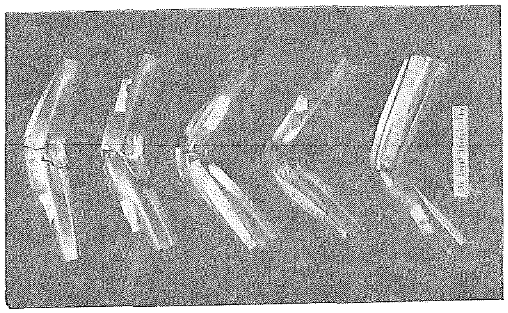

FIG.14 local Instability of the SPF Specimens

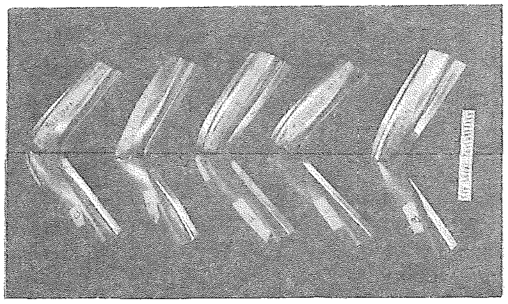

FIG.15 Local Instability of the STF Specimens

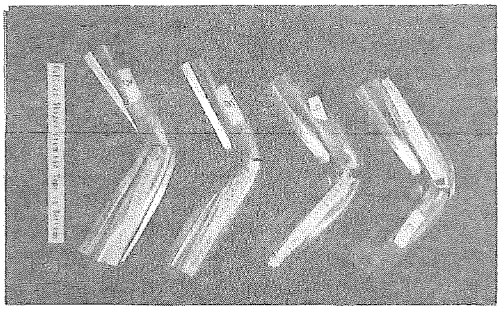

FIG.16 Failure of the Specimens in the Middle from the Tops to Bottoms of the Hat-Section Specimens

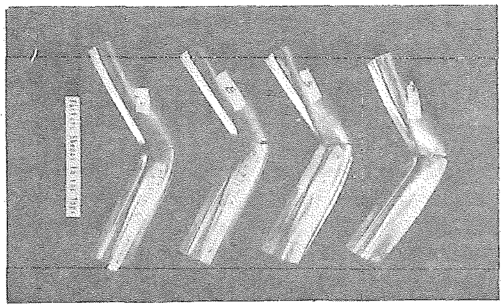

FIG.17 Failure in the Middle on the Tops of the Hat-Section Specimens

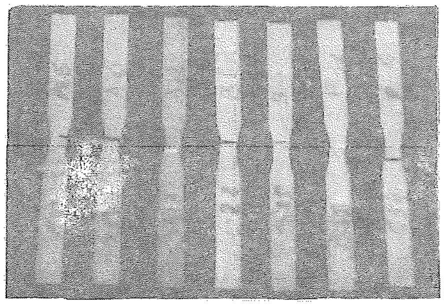

FIG.18 Fracture Modes of Fatigue Test Sheets

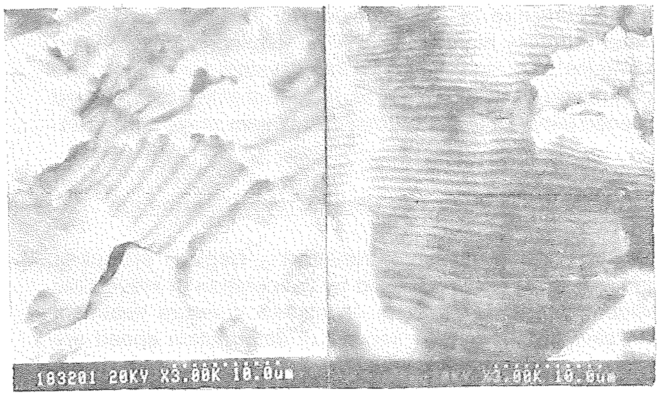

FIG.19 Microstructure of Fatigue Fracture A' 7475 SPF Specimen

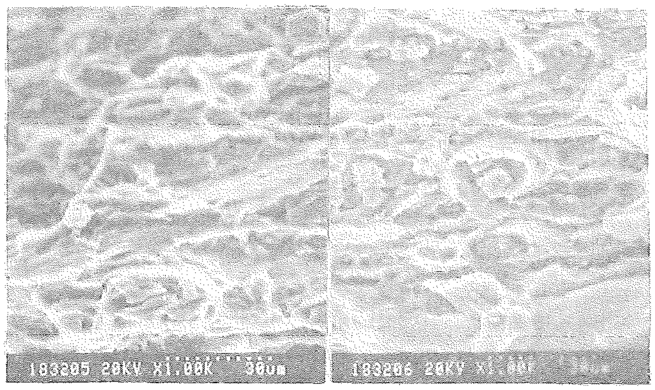

FIG.20 Microstructure of Fatigue Fracture B' 7475 STF Specimen

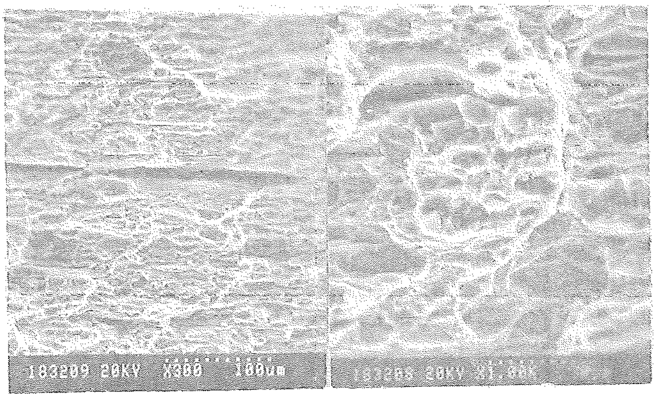

FIG.21 Microstructure of Fatigue Fracture D' Lc4 STF Specimen